Study and application of biopolymers in the field of agricultural and environmental engineering: review

Víctor Adán Cepeda-Tovar[*a], Anilú Rubio-Ríos[a], Lorena Farias-Cepeda[a], Juan Roberto Benavente-Valdés[a], Leopoldo Javier Ríos-González[a], Francisco Javier Enríquez-Medrano[b]

[a]Autonomous University of Coahuila. Faculty of Chemical Sciences, Blvd. V. Carranza S/N, 25280, Saltillo, Coahuila, México.

[b] Applied Chemistry Research Center, Enrique Reyna H. No. 140, San José de los Cerritos, 25294 Saltillo, Coahuila, México.

Estudio y aplicación de biopolímeros en el campo de la ingeniería agrícola y ambiental: revisión.

Estudi i aplicació de biopolímers en l'àmbit de l'enginyeria agraria i ambiental: revisió

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ABSTRACT

At present, a reduction in the production of materials that affect the environment is necessary. An example is conventional plastics that, when used and discarded incorrectly, harm ecosystems, a situation that focuses scientific research on the study of biopolymers as a sustainable alternative, that is, because they are compounds extracted from nature with properties biodegradable, antimicrobial activity and low toxicity, among others; which makes them suitable for different applications. Natural polymers have been used for several years in fields of medical and pharmaceutical science, due to the versatility of their mechanical, biodegradable and biocompatible qualities for the agro-industrial and agricultural fields. These biomaterials have been adapted to partially or gradually replace petroleum-based polymers in applications or uses such as food packaging, additives, water treatment, fertilizers, industrial plastics, absorbent materials, and biosensors. In this review, a detailed bibliographic analysis of the characteristics and applications of biopolymers in the field of agricultural and industrial engineering was carried out.

Keywords: Biopolymers, agroindustrial, biodegradable, plastics.

RESUMEN

En la actualidad es necesaria una reducción en la producción de materiales que afectan al medio ambiente. Un ejemplo son los plásticos convencionales que, utilizados y desechados incorrectamente, dañan los ecosistemas, situación que centra la investigación científica en el estudio de los biopolímeros como una alternativa sustentable, es decir, porque son compuestos extraídos de la naturaleza con propiedades biodegradables, actividad antimicrobiana y baja. toxicidad, entre otros; lo que los hace adecuados para diferentes aplicaciones. Los polímeros naturales han sido utilizados desde hace varios años en los campos de la ciencia médica y farmacéutica, debido a la versatilidad de sus cualidades mecánicas, biodegradables y biocompatibles para el ámbito agroindustrial y agrícola. Estos biomateriales se han adaptado para sustituir parcial o gradualmente a los polímeros derivados del petróleo en aplicaciones o usos como envasado de alimentos, aditivos, tratamiento de agua, fertilizantes, plásticos industriales, materiales absorbentes y biosensores. En esta revisión se realizó un análisis bibliográfico detallado de las características y aplicaciones de los biopolímeros en el campo de la ingeniería agrícola e industrial.

Palabras clave: Biopolímeros, agroindustriales, biodegradables, plásticos.

*Corresponding author:v_cepeda_tovar@uadec.edu.mx

RESUM:

Actualment, és necessària una reducció de la producció de materials que afecten el medi ambient. Un exemple són els plàstics convencionals que, quan s'utilitzen i es descarten de manera incorrecta, perjudiquen els ecosistemes, una situació que centra la investigació científica en l'estudi dels biopolímers com a alternativa sostenible, és a dir, perquè són compostos extrets de la natura amb propietats biodegradables, activitat antimicrobiana i baixa. toxicitat, entre d'altres; que els fa aptes per a diferents aplicacions. Els polímers naturals s'utilitzen des de fa diversos anys en els camps de la ciència mèdica i farmacèutica, per la versatilitat de les seves qualitats mecàniques, biodegradables i biocompatibles per als camps agroindustrial i agrícola. Aquests biomaterials s'han adaptat per substituir parcialment o gradualment els polímers derivats del petroli en aplicacions o usos com ara envasos d'aliments, additius, tractament d'aigües, fertilitzants, plàstics industrials, materials absorbents i biosensors. En aquesta revisió s'ha realitzat una anàlisi bibliogràfica detallada de les característiques i aplicacions dels biopolímers en l'àmbit de l'enginyeria agrícola i industrial.

Paraules clau: Biopolímers, agroindustrials, biodegradables, plàstics.

INTRODUCTION

Biopolymers

Biopolymers are substances produced by living organisms, such as plants, animals and microorganisms, they are synthesized by chemical and/or biological agents (for example, processing enzymes), or through processes such as fermentation or by polymerization of biomolecules of low molecular weight with appropriate functional groups, generating some basic components such as sugars, amino acids or hydroxylated fatty acids to form high molecular weight molecules. However, synthetic biopolymers have also been created, such as polystyrene (PS), acrylic polymers (PMMA, PBuA, etc.), polyamides (Nylon 6, Nylon 6.6), polysulfones (PSu) and polychloride. vinyl (PVC), among others. They are also biocompatible, since they are degraded within the body in the presence of enzymes and natural processes are reabsorbed without side effects in biological systems. These properties of biopolymers are being exploited by the medical field for drug delivery and tissue engineering (Ashish et al., 2020; Chang et al., 2020). The most important properties of biopolymers are: low density, high molecular weight, biocompatibility, innocuousness, easy sterilization, it has very poor mechanical properties, as well as the water absorption capacity is considerably varied and slow degradation, among others. Thus showing a wide spectrum of applications, since they are suitable for use as prostheses, joints, implants, in surgical equipment and instruments, and also as bone cements, membranes and as components of artificial organs (Majee et al., 2017; Blachechen et al. coll., 2020). Figure 1 lists a classification of biopolymers based on their biodegradability, as well as Table 1, the main more general applications for biopolymers for commercial use are listed.

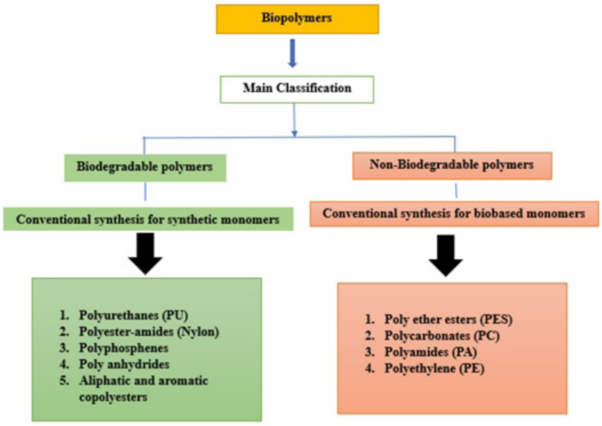

Figure 1. *General classification of the main biopolymers considered biodegradable and non-biodegradable.*

Table 1. *Applications of biopolymers for commercial use (Ashish et al., 2020).*

Biopolymer	Chemical family	Applications
Poly(3-hidroxybutyrate)	Polyhydroxyalkanoates	Disposable films, gloves, medical
Poly (lactic acid)	Poly-(hidroxi-acid)	Food Packaging, bags, cutlery products, sheets, mats, containers
Poly dioxanone	Poly-(ether-ester)	Medical sutures and implants for slow
Poly(ethylene carbonate)	Aliphatic Polycarbonates	Food packaging films, sacrificial Processing materials
Nylon	Polyamides	Textile and plastic consumer products, fibers
Poly(ether-urethanes)	Polyurethanes	Applications such as foams and linings, and absorbent materials
Poly(Vinyl Alcohol) Poly(Vinyl Chloride)	Vinyl polymers	Plastic tubes, films, bottles, wire
		Insulation packaging bags

Applications of biopolymers in tissue engineering

In the field of tissue engineering, there is a special type of polymers, known as smart polymers, exemplifying polyacrylic acid (PAc), polyvinyl pyrrolidone (PVP), methacrylic copolymers (PBuA, PMMA, PBMA), among others; this because they respond to stimuli, since they contain functional groups in their structure which act as a switch. Among the polymers used in this medical practice, the following examples stand out: polylactic acid (PLA), collagen, fibroin, chitin and chitosan (Rani et al., 2020). These are biocompatible, non-thrombogenic, flexible, resistant and easy to mold. These characteristics make them ideal candidates for various applications in the biomedical field, such as tissue engineering, bone tissue engineering, 3D endothelialization, artificial blood veins, 3D cell patterning, drug delivery, orthodontics, wound healing and closure, microsurgery. , contraceptive materials, vascular repair devices and stents for aneurysm treatment, among others (see Figure 2) (Moradali & Rehm, 2020; Reimer & Tranquillo, 2018; Davidson Hernandez & Reyes-Romero, 2019; Osorio-Delgado et al., 2017).

An example of a smart biopolymer for a medical application is the Kefiran extract, which is a polysaccharide of microbial origin that is extracted from Kefir grains. For this particular compound, it has been shown that it can be an excellent candidate to promote tissue repair and regeneration (Radhouani et al., 2018). A second example is polylactic acid-co-polyglycolic acid copolymers, which have been used as orthopedic implants, as plates or screws for the treatment of fractures and to fill bone defects, as well as scaffolds to facilitate bone formation. new (Rebelo et al., 2017).

On the other hand, poly(hydroxybutyrate) and its synthetic counterparts have drawn the attention of researchers due to their biocompatibility, non-toxicity, and intrinsic biodegradability. It is widely used in the biomedical sector, as a drug carrier, tissue engineering scaffolds, and in resorbable devices such as cardiovascular grafts, among other applications (Rebelo et al., 2017; Pattanashetti et al., 2017).

In the area of lung tissue engineering, the goal is to rebuild parts of the tissue and repair the physiological functions of the lung that become dysfunctional after disease or injury. In this sense, Noutsios & Pantazaki, in 2018, used biopolymers such as collagen and matrigel, which demonstrated that these biopolymers allow the growth of lung tissue, although the development of a fully functional organ has not been proven.

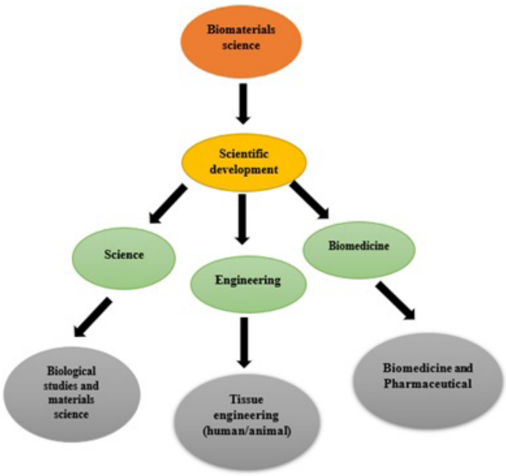

Figure 2. *Schematic representation of the main contributions of the science of biomaterials.*

Nanostructured bioresorbable drug delivery systems that fight lung cancer and prevent metastasis are also used. Furthermore, biopolymers have application as substitutes for pulmonary surfactant in acute respiratory distress syndrome. In addition, Pawłowska et al. in 2018 proposed the use of biopolymers as surgical implants in pulmonary blood vessels. Furthermore, antibiotics have been encapsulated in polymeric nanoparticles for lung gene therapy in the context of modulating the function of alveolar macrophages, dendritic cells, and adaptive immune responses (Pawłowska et al., 2018).

Development of biopolymers in the area of food engineering

Biopolymers are derived from natural sources such as plants, animals, microbes, as well as algae and agro-industrial waste (Flaris & Singh, 2009). Agricultural sources of biopolymers are corn, rice, wheat, potatoes, sorghum, yams, cassava, banana, tapioca, cotton, and barley, while animal sources include pigs, cattle, etc. (Flaris & Singh, 2009). Biomass-derived sources include agricultural residues, crops, paper waste, wood waste, and green waste, while marine sources include corals, sponges, fish, lobsters, shrimp, etc. (Devadas et al., 2021; Vickers, 2017).

Biopolymers such as collagen, keratin, chitosan, silk and elastin have been mixed with synthetic polymers to prepare biocomposites with improved characteristics, which has generated great interest towards various biocomposites in different fields due to their characteristics and easy commercialization. Biopolymers are in great demand as packaging films, which can be used in the medical area, pharmaceuticals, and food (Lu et al., 2016; López et al., 2020; Hassan et al., 2019). In the field of food, there can be three main applications of biopolymers and their compounds such as food emulsion, edible films and packaging materials.

Proteins or polysaccharides are biopolymers that can form bonds, complexes or chelators to modify their flow properties and are generally used as emulsifying, encapsulating and stabilizing agents useful in the formation of gels, films, emulsions, stabilizers and thickeners in the food industry. Many of them can be consumed as edible films or as additives due to their fat content, water retention capacity, diffusivity, texture, and appearance (Chronakis & Kasapis, 1995).

In this sense, emulsions or colloidal dispersions have been considered as immiscible liquids, where one of them is found as the continuous phase and the other is finely divided into drops (dispersed phase), the size of the drops can be micrometric. or nanometric. Some examples of this type of dispersions in the food industry are: milk, yogurt, cheese, cream, mayonnaise, butter, etc. Milk is a commonly used functional biopolymer that is used as an ingredient in the production of other food products such as sauces, dressings, butters and creams, etc. Functional biopolymers are mainly used in the production of complex food products due to their rigid oil-in-water structure, emulsion-forming properties. Proteins from products such as milk, eggs, fish; and polysaccharides such as xanthan gum, modified cellulose, and starches act as beneficial emulsions, due to their ease of adherence and their functional properties that produce greater surface charge, pressure, adsorption kinetics, droplet stability, and affinity, which facilitates marketing. of products with a slogan of being "consumer friendly" (McClements, 2009).

Biopolymers considered as reduced fat products, for example oil-in-water emulsions are replaced by water-in-water emulsions, commonly called double emulsions.

To keep the double emulsions stable, a protein-polysaccharide combination is used, acting as stabilizers for the internal and external phases of the liquids, thus reducing the fat in the products developed (Dickinson, 2011).

Emulsions from rice bran oil coated with biopolymer emulsifiers such as modified starch and whey protein isolate have shown stability to lipid oxidation. This knowledge could be implicated in the commercialization of food products with lipid phases (Charoen et al., 2012).

From the ecological-environmental point of view, packaging materials for food products from synthetic sources were mostly used worldwide, which aroused great attention towards environmental safety, which led to interest in developing new degradable and sustainable packaging materials. / or biodegradable based mainly on sustainable sources of plant or animal origin.

Due to the poor mechanical properties that biopolymers present, they have been combined with other natural or synthetic polymers to form compounds and nanocomposites to improve the mechanical properties of biopolymers in addition to modifying their resistance to water and other solvents. Associated with this, the development of active and intelligent foods for the packaging of various products has also been achieved through conventional encapsulation and nano-encapsulation technologies (Fabra et al., 2014; Rhim & Ng, 2007).

Polysaccharides obtained from plant resources such as cellulose, starch, chitin, chitosan, pectin, protein-based biopolymers such as wheat gluten, soy protein, gelatin, corn zein and milk protein such as whey were treated, processed, melted and dried to form different packaging materials. Other biopolymers such as polylactic acid (PLA), hyaluronic acid (HA), together with other biopolymer blends, for example starch/PLA/Polyvinyl alcohol (PVA), have been used to obtain stable and uniform films (Udayakumar et al., 2020). Biopolymeric nanocomposites based on starch, cellulose, pectin, gluten, soy protein, gelatin, were coated with PLA showing effective properties, providing a wide range of improvements in physical, mechanical, thermal and antimicrobial properties (Udayakumar et al., 2020; Ghanbarzadeh et al., 2015). Some barrier properties against water vapor, oxygen, carbon dioxide and flavor lead to an increase in the production of these compounds for food packaging (Ghanbarzadeh et al., 2015; Tang et al., 2012). Table 2 lists the properties of biopolymers and biocomposites formulated as films for food products.

Complementing the above, starch and PLA have demonstrated extensive properties as bio-nanocomposites with the addition of nanometer-sized fillers, for example, montmorillonite, silver and zinc oxide (ZnO). Despite the lack of toxicological studies on nanofillers performed, these compounds exhibit antimicrobial and oxygen scavenging properties along with the conventional properties of a packaging material, which are essential for extending the shelf life of food products (Othman, 2014).

To enhance the antimicrobial property of biodegradable polymers, extracts found in agricultural waste, plants, and other essential oils produced growth inhibition of many bacteria, both gram-positive and gram-negative (Muthuraj et al., 2015).). To carry out the tests, PLA matrices and alginate films were prepared, to which additives were added that allowed the release of the bioactive components to inhibit the growth of the bacteria on the surface of the food product, thus extending its total duration. Biodegradable polymers with suitable compatibilizers were added to be used as compounds for packaging applications (Muthuraj et al., 2015; Valdés et al., 2014).

Seen from the perspective of food, biopolymers are also used in the preparation of films for use as edible packaging that covers food products. These edible films can be consumed together with food, since they are basically prepared from proteins and polysaccharides (Han, 2013).

Natural sources of antimicrobial agents such as organic acids and essential oils were accepted as GRAS (generally recommended as safe), which were coated with biopolymer derivatives from algae, starch, cellulose, gums, and their respective mixtures. Edible polysaccharide and protein films appear transparent due to the use of hydrocolloids (Campos et al., 2011).

Edible whey protein-based biofilms produced with the addition of concentrations of calcium (Ca^{+2}) and glycerol ($C_3H_8O_3$) ions showed an improvement in their tensile, elongation, and water vapor permeability mechanical properties. Furthermore, these semitransparent mem-

Table 2. *Properties of biopolymers and composites in food films (Own Authorship).*

Biopolymer /Biocomposite	Preparation película	Barrier against oxygen	Moisture barrier
starch	Watery	Moderate	Poor
Chitosan	Watery	Good	Poor
cellulose	Extrusión	Poor	Moderate
Gluten	Watery in Ethanol	Good	Moderate
Soy protein	Watery	Good	Poor
Polylactic Acid (PLA)	Extrusión	Moderate	Moderate
Starch Nanocomposites	Watery/Extrusión	N/A	Moderate
PLA Nanocomposites	Watery/Extrusión	N/A	Good

N/A: No apply

branes consisting of whey protein aggregates could also resist ultraviolet light, as reported in the literature (Fang et al., 2002).

A certain amount of cellulose nanofibers was added to an edible film of mango puree which significantly increased the tensile properties and the glass transition temperature of the material (Tg). Likewise, they showed a drastic change in the elongation of the biofilm, which produced an increase in the barrier properties against water (Tavassoli-Kafrani et al., 2016; Azeredo et al., 2009). Recently, poly-γ-glutamic acid (γ-PGA) was produced biologically using the Bacillus subtilis strain, in this study an immunomodulatory effect was shown due to the presence of high molecular weight (HMW) compounds useful for packaging and food processing (Azeredo et al., 2009; Sung et al., 2005; Prameela et al., 2018).

Biopolymers with agricultural applications

The various productive activities of society require specific materials that meet the objectives and/or needs for which they have been designed, however, some materials turn out to be efficient and durable but harmful to nature, so current research is They are focused on continuing to provide optimal materials, with environmentally friendly characteristics, in order to reduce the ecological footprint that synthetic polymers leave on the planet.

Biopolymers are polymeric materials obtained from renewable natural sources, whether of plant or animal origin or synthesized by microorganisms, so the environmental impact of their production is reduced, compared to the synthetic polymers usually used in different industries. However, one of the disadvantages of these materials is the high costs of production and transformation. Despite this, biopolymers have taken on great relevance in different productive sectors since they retain some characteristics of polymers of fossil origin, such as resistance, malleability and innocuousness. The aforementioned characteristics can be improved by crosslinking biopolymers with other materials, either synthetic or of natural origin (Valero-Valdivieso et al., 2013).

Within the agricultural sector, the use of polymers has been widely explored since ancient times, one of the main applications of these materials in the agricultural sector is focused on the retention and dosing of water in ornamental, horticultural, and forestry plants, etc. (Nadarajan & Sukumaran, 2021).

Currently, the focus on the use of polymers in the agricultural sector seeks to reduce the problems associated with intensive agriculture, such as the excessive use of fertilizers (nitrogen, phosphate, potassium, etc.), pesticides, pesticides, herbicides, etc. In addition to the above, it is sought that the polymers are increasingly enriched, in order to provide nutrients while acting as a water reservoir (Flynn et al., 2021).

Within the agricultural sector, polymer-based hydrogels have been used regularly, however, the excessive use of these materials has meant a serious contamination problem, since at the beginning of development and use the hydrogels were designed based on polymers. synthetics such as polyacrylamide, polyacrylates, polyvinyl alcohol and polysiloxanes, which due to their chemical structure have zero or very low biodegradability properties. Hydrogels can be defined as specifically crosslinked polymeric matrices between two or more components and are characterized by retaining large volumes of water inside the structure (Dhanapal et al., 2021).

Currently, the development of materials with applications in crops is directed towards the substitution or reduction of the use of synthetic polymers, which is why various applications have been developed using biopolymers such as starch, chitin, chitosan, cellulose, alginate, guar gum, gum arabic, xanthan gum, pectin, among many others (Ai et al., 2021; Panpinit et al., 2020; Kaith et al., 2017).

These biopolymers have a chemical composition that allows crosslinking either with another polymer, or with synthetic polymers, with which the chemical and structural characteristics of both materials can be improved, which will provide composites with better properties (Ahmad et al., 2019 ; Ghobashy, 2020; Shin et al. 2020).

One of the most abundant biopolymers on earth is chitin, being second only to cellulose and can be obtained through a process of deacetylation of the precursor chitin that can be found mainly in the shell of crustaceans, the squid feather. , the cell wall of fungi and in the exoskeleton of some insects.

Chitosan shows bactericidal and fungicidal properties, which is why it is widely used in the agricultural field, in addition to being used as a fruit coating to control postharvest deterioration and thus increase storage time. In addition, it is used as a matrix in the controlled release of fertilizers and chemicals to combat pests. Work continues with chitosan for the preparation of fertilizer encapsulation covers to control its release into the soil and improve its efficiency (Bauer et al., 2022; Pérez et al., 2017).

Biopolymers with applications in environmental bioremediation

Some of the fields of application of these materials are focused on retaining, mitigating or eliminating the impact of environmental pollution that has been generated over years of overproduction of single-use toiletries. Some of the applications of these materials are aimed at the adsorption of pollutants, since the structural characteristics of biopolymers allow the reactive groups present in them to act as adsorbents for pollutants of organic (for example, dyes) and inorganic (for example, dyes) origin. example, heavy metals). Some of the biopolymers typically used for this purpose are cellulose, alginate, chitosan, starch, etc. (Angamarca Yaguana & Delgado Valladares, 2022).

Over the years, the techniques to encapsulate, degrade or eliminate contaminants have been renewed, seeking to use materials that are efficient and that do not represent a greater danger to humans or the environment. Among these techniques, adsorption can be highlighted, which can be defined as a process in which a gas or liquid accumulates on the surface of a solid or liquid (adsorbent), allowing the formation of a molecular or atomic film (adsorbate). (Burciaga-Montemayor et al., 2020). The key component for the optimal functioning of this technique is the adsorbent, which must be designed based on the contaminant to be removed, its concentration, and the conditions in which it is present (solid, liquid or gas). Under the premise of reducing harmful impacts on the environment, the adsorbent must meet the following characteristics: it must not be toxic, precursors of natural origin, easy to process, and it can be regenerated or reused (Kennedy et al., 2018).

Within the development and continuous improvement of the adsorption technique, the objective of improving adsorption capacities has been established, so research in this area has focused on exploring the properties of different materials, some of which come from waste as common as the skin of fruits and vegetables, including waste from the processing of food of animal origin (Colina et al., 2014), which, due to its chemical structure and physical properties, are feasible to form functional polymeric materials. Within bioremediation, different materials based on biopolymers have been highlighted, such as PVA crosslinked with BNNF (Boron Nitride Nanofibers), with which a kind of foamy composite is obtained that presents a series of honeycomb-shaped networks, which allows contaminants such as cationic dyes, CO_2 and even the removal of oils in aqueous medium to be retained within these cavities (Gao et al., 2020).

Within the bioremediation of soil and water, a new water retention method for unsaturated soils was developed by adding biopolymers, with the result that by including 1% xanthan gum, the water content can be increased by up to 25%. unsaturated. Derived from this study, it was also possible to identify that the use of guar gum increases the resistance of the soil, in addition to functioning as an efficient flocculant in wastewater treatment (Flores Valdez et al., 2022).

In addition to this, there are several conventional techniques for the development of new technologies that are of great vitality in the treatment, recycling and availability of wastewater. It is at this point that polymers have been used largely in many industries due to their unique characteristics (depending on the end use and both their physical and chemical properties). Biopolymers resemble a natural alternative to synthetic polymers that can be prepared by linking monomeric units in a covalent or coordinated covalent manner. The review carried out by Yaashikaa and collaborators in 2022 focuses on the topic of biopolymers and derivatives of these compounds as suitable adsorbent materials to eliminate contaminants present in the environment, mainly in aquifers. In this work, the classification of these biopolymers, the preparation methods and their possible applications in a very general way were analyzed in detail. Biopolymers have an alternative potential that impacts by replacing conventional adsorbents with new generation adsorbents. In addition, alternative materials to membranes (such as biopolymers) and their effective methods of employment as suitable adsorbent materials are briefly discussed. Highlighting regeneration and reuse methods based on biopolymers. This review concludes the research that will serve in the future by improving recent trends in the application of biopolymers in various fields, based on economic and ecological perspectives.

One of the most centralized concepts in environmental bioremediation processes, it has focused efforts on biostimulation (also called microbial stimulation), considered the most effective bioremediation strategy, which is why it is widely used in agricultural fields, phytotechnics, agro-industrial, etc. ; standing out for its simplicity and low cost. In the biostimulation process, polymeric controlled nutrient release systems (SRN) are used. The use of biopolymeric systems ensures biodegradability properties, low cost and low toxicity compared to those generated from synthetic sources. Despite advances in studies with natural polymers, few are used as nutrient releasers, or bioactive compounds rich in certain substances for bioremediation applications. Current scientific reports still fall short of the relationship with the release efficiency and effects on microbial growth and degradation of xenobiotic compounds. In this work, De Carvalho and collaborators in 2021 explored the results and advances of these biopolymeric systems used in SRN and their future perspectives in various bioremediation processes.

The high consumption of primary resources and production of waste is increasing progressively and seriously, causing an impact on the environment and ecosystems. Environmental pollution derived from daily activities currently causes a serious problem that afflicts our planet. In this sense, one of the most challenging tasks of the 21st century is the development of new ecological, sustainable and economically viable technologies to clean the environment; this is where the area of nanotechnology comes in. The formulation of high-performance nanomaterials, thanks to their unique characteristics, allows them to chemically modulate their properties, which represent a potential for the development of sustainable, advanced and highly innovative products. In this review, Rando and collaborators in 2022 showed the most recent innovations in environmental recovery strategies for certain areas, using different nanocomposites, in combination with bioremediation techniques. The manuscript focuses its efforts on obtaining regenerable nanomaterials, as well as their design properties that allow supporting the latest research and innovations on sustainable strategies in the field of environmentally friendly bioremediation.

The formulation of plastics from synthetic sources and their exponential use, such as packaging, household items, medical applications and beauty products, has caused a global problem. The various impacts that these synthetic materials produce on health, well-being and the environment are another problem that society faces today. The contribution of biopolymers has made it possible to obtain these biocomposites considered a highly sustainable alternative in their various applications. A clear example of biopolymers are polyhydroxyalkanoates (PHA), which are considerably degradable materials. However, other polymers, such as polylactic acid (PLA), are partially degradable and often biosynthesizable. The contribution shown by Awasthi and collaborators in 2022, the biodegradation of polymers using microorganisms is considered a highly effective bioremediation approach. It is in this sense that the present review analyzes the production of these biopolymers, their persistence in the environment, their basic biodegradation conditions (anaerobic and aerobic), and finally the challenges associated with biodegradation and future perspectives. Taking into account technologies aimed at the production of biopolymers and their biodegradation.

Finally, in environmental bioremediation processes, traditional soil methods are usually associated with high energy consumption, carbon emissions, and long-term environmental impact. Recent developments have demonstrated the potential use of biologically based techniques as ecological alternatives for the stabilization of various soil types (considering region, climate, etc.). The work carried out by Correia and collaborators in 2023, based their studies on the effects of the addition of biopolymers, exemplifying xanthan gum (XG) and carboxymethyl cellulose (CMC) in soils with waste from mining sources. For these composites, unconfined compressive strength tests were carried out on previously collected samples (previously treatments were carried out, being two cycles of percolation, extraction and homogenization) to evaluate whether biostimulation and bioremediation remain active. The results shown by the authors allowed us to conclude that both biopolymers, when applied individually (contents close to 1%), are effective stabilizers, with CMC being the compound that allows increases in compression resistance close to 109%), showing better results. for CMC than for Portland cement. In addition to this, good results were observed when bioaugmentation was combined with xanthan gum, improving unlimited compressive strength of up to 27%. The study revealed that these bio-based techniques are promising soil engineering techniques, offering environmentally friendly alternatives for sustainable soil improvement, contributing to a greener and more sustainable future.

CONCLUSIONS

The standards and requirements that are aimed at resolving or mitigating the high production of compounds of synthetic origin, produce advances towards the growth of modern materials and processes that are in tune with complying with the well-being of the natural habitat. This allows scientists, academics, and researchers to integrate bioresources into the construction of new components and products that meet the aforementioned concerns and minimize reliance on fossil fuel-derived components. Likewise, the development of biopolymers and their compounds has received a prominent role; however, it is still in its early stages. Although there is a great need to generate eco-friendly products, their still low yields and high development costs weigh on their production compared to conventional synthetic polymers. Due to this reason, in recent years, there has been an increase in the amount of work devoted to creating new products using bioresources that aim to eliminate these drawbacks. This review shows a general description of biopolymers, covering the main topics related to their types and general applications of these materials in fields that have revolutionized the field of science and technology, mentioning the engineering, agricultural, food, pharmaceutical , etc. The products developed will gradually have the ability to be composed of highly competent sustainable sources to meet the needs for a wide range of applications. Likewise, the aforementioned biopolymers can be obtained from various synthesis methods, creating increased opportunities to inculcate the development and utilization of biobased polymeric compounds.

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